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Art. IX.—*Possibilities of Modifying Climate by Human Agency, with Special Application to South-Eastern Australia.*

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Many attempts have been made by more or less violent means to compel the atmosphere over dry areas to part with its moisture, and all have been futile. In the following paper, evidence is brought to show that methods more in accord with Nature's requirements are actually successful.

The proofs, or evidences, are mainly dependent upon the rainfall data controlled by the Commonwealth Meteorological Service, and deal only with the Southern parts of Australia.

The most important climatic conditions in any one latitude are in general dependent upon the distribution of land and water areas. As this is mainly so on account of the difference in evaporation from them, we may substitute for water areas the term "evaporation areas." It is possible to conceive of sufficient evaporation for abundant rains from areas remote from the ocean, though, of course, under the planetary condition of atmospheric circulation, it may be impossible to make any inland district absolutely self-contained as regards its water vapour. Evaporation results have shown that a land surface, if well grassed, may give rise to greater evaporation than a water surface. This is also probably true of forest coverings in the ordinarily moist climatic regions, though not, I think, of forests in countries subject to prolonged droughts, times of very low humidity, and high temperatures, such as is the case in inland Australia. Our forest vegetation has to become specially adapted to meet drought contingencies. Taking, for example, the forest covering of our Mallee districts, consisting mainly of various species of dwarf Eucalypts, one cannot fail to be struck by its unmoved appearance after the worst of droughts, even the 18 months' drought of 1913-14-15, and the serious summer drought of 1911-12, leaving the trees as fresh looking as ever. Of course, there was probably not the usual amount of growth, but the trees had not lost much of their vitality.

Quite apart from the results of experiment in measuring plant transpiration, it would thus appear obvious that these trees possess remarkable control over their rate of transpiration, such that at the first hint of drought pressure, they declare a state of siege by closing their stomata. Assuming that they do this during the first warmth of spring they will contribute little towards the humidity of the atmosphere during the periods of east to north winds and falling barometers preceding the approachng " lows." They are too much on the defensive to aid in rain production.

This is, however, not the case with growing crops, such as wheat, oats, etc., which obviously wilt in the hot winds, or with most of the grasses. As one of the main objects of cultivation in the dry areas is to store moisture in the soil for the use of the growing cereal crops, it is almost essential for successful cropping that the land should lie fallow for twelve months, and be occasionally worked to prevent weed growths dissipating the water content of the subsoil, and, as this is drawn upon most in the spring months, the plants must then transpire freely. They, therefore, contribute generously to the atmospheric humidity, and so aid in producing conditions favourable for rain. This reasoning suggested a test. If this is correct, stations in the older Mallee areas, or those in the south-eastern edge of the cultivation area, which is gradually increasing by encroachment upon the Mallee in a north-westerly direction, might be expected to show some slight improvement in their spring conditions as compared with old stations beyond which no great advance has yet been made. This might be shown by rainfall or temperature, or by both.

To test the matter, the following groups of stations were chosen:—Tyrrell Downs, Swan Hill, and Kerang to represent the remoter and least benefited portion; Charlton, Lake Marmal and Wychitella South, the area which might be the gainer from the substitution to north-westward of cereal crops and grass for Mallee scrub. The area separating the two groups is about 55 miles across. Kerang was assumed to be too far north to benefit, but both that station and Swan Hill are south-east from areas being rapidly developed by irrigation, and should be in a different category in the years to come. All of these stations have rainfall records as far back as 1885, and this was chosen as the starting point. Comparisons were made of the mean rainfalls for the three following decades, 1885-94, 1895-1904, 1905-1914. The results were quite favourable to the theory. Two groups of spring months were chosen—September and October, and

August to November, though the last might possibly have been better with November out of it, as in some years the grass is dry, and the crops nearly ripe long before the month is ended. The rainfalls for these periods were expressed as percentages of the annual amount, and these are shown in the following tables:—

(a) STATIONS TOO FAR NORTH OR NORTH-WEST TO BENEFIT BY SPREAD OF CULTIVATION.

Period.	Swan Hill. Percentage of Annual Rainfall.		Kerang. Percentage of Annual Rainfall.		Tyrell Downs. Percentage of Annual Rainfall.	
	Sept.-Oct.	Aug.-Nov.	Sept.-Oct.	Aug.-Nov.	Sept.-Oct.	Aug.-Nov.
1885-1894 -	18-1 -	38·4	18·4 -	35·7	18·6 -	39·3
1895-1904 -	17·7 -	32·7	17·9 -	36·0	15·8 -	35·0
1905-1914 -	16·1 -	31·5	15·7 -	30·4	17·4 -	32·3

(b) STATIONS BENEFITTING, IF AT ALL, BY SPREAD OF CULTIVATION.

Period.	Lake Marmal. Percentage of Annual Rainfall.		Wychitella S. Percentage of Annual Rainfall.		Charlton. Percentage of Annual Rainfall.	
	Sept.-Oct.	Aug.-Nov.	Sept.-Oct.	Aug.-Nov.	Sept.-Oct.	Aug.-Nov.
1885-1894 -	18·4 -	38·5	16·76 -	36·25	17·7 -	36·5
1895-1904 -	19·5 -	36·5	17·8 -	34·5	19·16 -	34·5
1905-1914 -	19·05 -	35-1	18·5 -	33·9	17·96 -	33·5

In the first group the September-October rains declined by 2.0, 2.7, and 1.2 per cent., giving a mean decrease of 2 per cent. In the second group there were increases of 0.65, 1.84 and 0.26 per cent., giving a mean rise of 0.9 per cent., or a relative gain for that period of about 3 per cent. of the annual total, or about *half an inch of rain.* For the four months' period for (a) we get decreases of 6.9, 5.3 and 7.0 per cent., giving a mean of 6.4 per cent. For (b) the declines were 3.4, 2.3 and 3.0 per cent., giving a mean of 2.9 per cent., or a relative gain of 3.5 per cent., thus suggesting that the benefit is not quite limited to the two months, September and October.

The assumption with regard to this selection is, of course, that in (a) we get simply the effects of periodic seasonal variation, and with (b) we get the periodic variation plus that due to the change of environment. If the deduction is correct, we have quite a marked improvement in spring conditions at Lake Marmal, Wychitella South, and Charlton, owing, we will say, to the evaporation from wheat and grass lands lying to north and west of them.

It might be said that any gain in the spring rainfall would be at the expense of the rains of other parts of the year. It is not probable, I think. As regards the three winter months—May, June and July—the smallness of the latitudinal temperature gradient, aided by the more rapid cooling of continental areas, enables even the most ordinary type of Antarctic disturbance to bring rain as far inland as the Murray River, and in summer thunderstorm tendencies over the Mallee will be greater with the alternation of ploughed fields and narrow timber belt than they would be with the uniformity of Mallee scrub, and its tendency to cool the lower levels of the atmosphere. The experience of aviators tends to confirm this last.

That the gain in this case was not confined to the spring months is evident by the following tables, showing the mean annual totals:—

	1885-94.	1895-04.	1905-14.
Swan Hill	15.15	11.20	12.28
Tyrrell Downs	15.91	10.36	11.45
Kerang	16.76	11.71	14.13
Means	15.94	11.09	12.62

	1885-94.	1895-04.	1905-14.
Charlton	18.59	14.01	16.55
Marmal	17.16	12.16	14.06
Wychitella	16.56	12.66	16.23
Means	17.44	12.94	14.95

Calling the first 1885-94 group mean A, and the second 1885-94 group mean B, the other means may be expressed as percentages of these as follows:—

A, .69 A, and .79 A, and B, .74 B, and .86 B.

These show relative gains of B over A of 5 per cent., and 7 per cent., or actual annual gains of about 0.9 and 1.2 inches.

It may be added that, in the selection of stations, no attempt was made to pick and choose. The first selection was the one used. Kerang is not, however, quite as well situated as the others for the purposes of this investigation, but it was the only other Victorian outpost station with long enough record. The results from two others might have been given. Waitchie, about midway between Tyrrell Downs and Swan Hill only goes back to 1893, but well supports the former, and Murray Downs, which is on the New South Wales side of the Murray, supports Swan Hill.

Substituting these for Kerang, we get the following results, which quite support the spring difference between the two rainfall groups, and indicate an even greater annual difference. The mean annual rainfall for the three successive decades for Swan Hill, Tyrrell Downs, Waitchie, and Murray Downs, are 15.6 in., 10.9 in., and 11.9 in., giving A, .69 A, and .76 A.

Creation of Water Surfaces.

It is perhaps not possible to store water in such amounts inland, as to distinctly increase the general humidity of the atmosphere, but " every little helps." It is possible that the rainfall averages along the shores of some of our land piercing inlets may be indicative of future possibilities. There are two very suitable for examination—Spencer's Gulf and Port Phillip Bay, and it fortunately happens that the shores of both are fairly well lined with rainfall stations.

The length of Spencer's Gulf is great compared with even its greatest width, hence winds bearing rains from the open ocean are confined to a small angle, and this is so nearly due south that but little rain could be brought in from that direction. Except near the entrance, where elevated land just inland from stations on the western shores of the Gulf gives these an increased rainfall, the western stations have a distinctly lower rainfall than the eastern ones. This difference appears to be about 2½ inches 50 miles from the entrance, where the Gulf has a width of about 70 miles, and slowly increases to 3 inches as far north at Pt. Broughton, where the distance from the entrance is about 130 miles, and the width 32 miles. Thence it diminishes to zero at the head of Port Augusta.

If Spencer's Gulf were silted up, it would be incredible that the rainfall on the resulting low level plain, especially in its northern portion, should be superior to that of, say, Yardea or Nonning, which stand on plateux of about 1000 feet in elevation to westward. As the average rainfalls of these stations are only about 10 inches, the rainfall near the head of the Gulf should almost certainly be less, say, about 8 inches. This would make the narrow strip of water forming the northern part of the Gulf responsible for an increase of 3 to 4 inches on the western shore, and 5 or 6 inches on the eastern.

For the sake of more definiteness as to the effect of evaporation from the waters at the head of the Gulf in increasing the rainfall, I have analysed the rainfalls at four of the stations with regard to the chief wind directions. The stations are Port Pirie and Hummock's Hill, Pt. Lowly and Germein. These form opposing pairs. Between Pt. Pirie and Hummock's Hill the

Gulf is about 19 miles wide, though, owing to coastal irregularities, the two places are about 28 miles apart. Point Lowly and Point Germein are 12 or 13 miles apart on opposite sides of the base of a narrow triangular water area, the apex of which is 45 miles further north. Owing to the way Pt. Lowly projects into the Gulf, it is only about 30 miles from Pt. Pirie, in a north-westerly direction. All four stations are practically at sea level. The wind directions were determined from the 9 a.m. weather charts, and it was, therefore, necessary to deal with the total wind change in 24 hours, which, of course, varied considerably. These total variations were grouped as follows: Winds veering (a) from north through west to south by west, (b) from north through west to west-south-west, (c) from between west-south-west and south by west, (d) winds with an easterly component (e) indeterminate, as in purely cyclonic circulations. Seven years' daily records were used, and the results for each year (1911-1917) are shown in the following table:—

Year.	N. through W. to S. by W.				N. through W. to W.S.W.				W.S.W. to S. by W.			
	Port Pirie.	Hummock's Hill.	Port Germein.	Point Lowly	Port Pirie.	Hummock's Hill.	Port Germein.	Point Lowly	Port Pirie.	Hummock's Hill.	Port Germein.	Point Lowly.
1911	159	114	162	65	157	25	87	56	293	157	324	177
1912	59	68	37	24	262	142	196	136	264	151	293	205
1913	94	67	63	43	254	94	229	158	138	29	124	31
1914	37	10	14	18	68	57	70	78	32	4	10	11
1915	7	—	6	—	392	238	340	228	221	89	210	159
1916	196	99	106	72	516	235	444	361	475	179	364	252
1917	108	49	72	63	582	369	432	374	165	48	98	72
Sums	660	407	460	285	2231	1160	1798	1391	1588	657	1423	907
Means	94	58	69	41	319	167	257	199	227	94	203	130

Year.	Easterlies.				Intermediate.				Annual Totals..			
	Port Pirie.	Hummock's Hill	Port Germein.	Point Lowly	Port Pirie.	Hummock's Hill.	Port Germein.	Point Lowly	Port Pirie.	Hummock's Hill.	Port Germein.	Point Lowly
1911	388	334	336	446	266	643	289	237	1275	1273	1201	1006
1912	366	533	421	405	346	331	268	218	1294	1224	1217	992
1913	265	465	242	300	262	278	214	258	1011	945	875	790
1914	479	777	415	552	213	131	167	179	836	986	695	839
1915	129	223	170	200	599	407	452	576	1348	958	1180	1183
1916	429	588	405	517	331	360	264	300	1950	1461	1598	1506
1917	391	582	361	472	717	552	612	650	1942	1600	1592	1632
Sums	2447	3502	2353	2892	2734	2702	2266	2418	9656	8447	8360	7948
Means	350	500	336	413	391	386	324	345	1379	1207	1194	1135

The results are very interesting. Comparing Port Pirie and Hummock's Hill we see that as regards winds from the western half-circle, half the total rain at Port Pirie comes with winds from between N. and W.S.W., and for these the average gain per annum over Hummock's Hill is 1½ inches, the rainfall being apparently increased by that amount and almost doubled by moisture taken up from a 20-mile stretch of water. The same proportion holds for the westerlies in general, which give 318 points to Hummock's Hill, and 640 to Port Pirie.

Now, taking the winds with easterly components, the gain to Hummock's Hill over Port Pirie is nearly as substantial, the Port Pirie rainfall of 3½ inches under easterly winds being raised to 5 inches from the moisture picked up in the passage over the water. This is perhaps even more than one would have expected as in some instances the rain clouds would be moving in a different direction from the surface winds, and would carry back to Port Pirie some of the added moisture.

Similar results are to be obtained from other comparisons. For example, taking Point Lowly and Port Germein; for winds between N. and W.S.W.—these not traversing the greater areas of the Gulf—the relative gain to Port Germein is 0.58 inch, and for easterlies, the relative gain to Pt. Lowly is 0.77, which is quite as much as one would expect considering the nearness of the two stations, and the way Pt. Lowly projects into the Gulf, enabling it to gain not only from easterly winds, but at times from northerly or even west-south-westerly winds.

It would thus appear that out of the ten inches of Port Pirie's rainfall under definite wind direction, at least 3¼ inches come from the adjacent waters, and if the same proportion holds for the indeterminate portion, the total gain will be at least 4½ inches. Hence, if the Gulf were silted up, its annual rainfall would not exceed 9 inches, and would probably be less, thus bearing out the previous more generally derived opinion.

The rainfall data from Port Phillip Bay are equally striking, stations on the Eastern shores receiving up to ten inches more than Western stations in the same latitude.

It is hardly necessary to remark that it is in rainy weather the principal additions to the rainfall must be made by local evaporation. Under generally anticyclonic conditions, as in some of our great drought years, the rains must largely fail; but the value of the increased amount in more favourable years is not thereby lessened.

In this latter respect Southern Australia enjoys a position different from that of some almost rainless countries, such as Egypt, where, in spite of irrigation on a grand scale, no marked increase of rainfall is observed. When the upper air has a humidity consistently much below that necessary for rainfall, the provision of any limited evaporation area is not likely to bring it up to the point of rain production, but in Southern Australia the upper air is sufficiently humid for a little rain with the passage of almost every Antarctic disturbance. This may help to explain the marked assistance which this paper suggests evaporation areas to have towards rainfall production. In the very dry central portion of the continent it might be much more difficult to trace such effects.

(2) By Irrigation.

In the south-eastern portion of the continent fairly extensive schemes have been brought to partial fruition, the chief of which are the fruit-growing areas at Mildura, Merbein, Renmark (in South Australia), and Curlwaa (in New South Wales), all near the extreme north-west corner of Victoria, and probably giving some 30,000 acres of fully irrigated lands. Then, upstream, along the Murray, are areas irrigated for lucerne and fruit at or near Swan Hill, Cohuna, Koondrook, etc., aggregating in 1912-13 some 90,000 acres. From the Goulburn some 60,000 acres more were irrigated in the same year. As most of this area would be rather dry in average years—certainly the 120,000 acres directly irrigated from the Murray and Loddon would be—there must be considerable evaporation from these, which would not be available under purely natural conditions. To these are being added considerable areas in Victoria, and the comparatively large Murrumbidgee irrigation areas in New South Wales supplied from the Burrinjuck reservoir.

These schemes have all been undertaken without reckoning upon any climatological improvement as the result. But it is probable that even from that point of view, we shall have interest for our money, and not simple, but compound, interest. If the rainfalls on the eastern and western shores of Spencer's Gulf and Port Phillip Bay are any guide, a 20 mile expanse of water may increase the rainfall by several inches, and, as the evaporation from irrigated areas is at least equal to that from ocean surfaces, and the irrigated areas are already large enough, stations to south-east and south from these should show some benefit from them, at all events during the chief growing season.

In dealing with the effects of sheets of water upon our own climate I have already shown the benefits derived by parts of South Australia from the Spencer Gulf, even as far north as Port Augusta, and especially around Germein Bay, from a sheet of water twenty miles across. Not many of our storages would compare in area even with this body of water, but it has to be remembered that the surface of the reservoir is multiplied many times by any effective scheme of irrigation. For example, the Burrinjuck reservoir has an area of only 20 square miles, but will hold at any one moment water enough to irrigate to a depth of one foot 771,000 acres, or 1200 square miles. If such an area as that could be irrigated, the evaporation resulting would be such as to have a most important effect not only upon the rainfall of the adjacent areas, but upon the precipitation over the area feeding the reservoir itself.

So far, only some 40,000 acres are occupied for the purpose for which this storage was made, but in Victoria in 1916 a total of 288,000 acres were under irrigated culture. When the 1,000,000 acre foot storages on the Upper Murray and the Sugar Loaf scheme on the Goulburn are added to the Burrinjuck, and the various other storages completed or projected, the area can be vastly increased.

Data from stations bordering on or within the irrigation areas give some indications of rainfall effects, but these are necessarily indefinite. The uncertainties as to the distribution of the areas under irrigation, the crops irrigated, whether of grass, wheat, lucerne, etc., and the variation in effect owing to differences in the character of the seasons, etc., make only very approximate estimates possible. Before 1891, when the Goulburn Weir was constructed the area of land irrigated must have been infinitesimal, and up till 1895, owing to abundant rains, there was little need for irrigation. The county of Rodney was the most favourably situated to make use of the Goulburn supplies, but this was not completely reticulated till 1904, by which time the Waranga basin was under construction. In 1904-5 the total area irrigated was 166,000 acres. Of this Rodney had 40,000, Tragowel 29,000; Cohuna 29,000, Macorna 11,000, Swan Hill 10,000, Wardilla 9000, etc. This rapid development was owing to the series of drought years which culminated in 1902. By 1906-7 the area was less, rose to 232,000 in 1907-8, another drought year, and fell to 130,000 in 1909-10, a very good season. Then, on to 1914, the increase was marked, and in 1913-4 reached 317,000 acres. Since then, or to April, 1918, there seems to have been little or no progress, the rainfall having been very abundant.

In attempting to show some possible effects of this upon the rainfall, one must assume that we have some groups of stations in the neighbourhood affected, and some unaffected by the evaporation from these areas. For the latter, I chose Echuca, Numurkah and Yarrawonga, which are all north or north-east from the principal area, though Echuca may now be affected by the Murray irrigation lower down. For the former we have Sheppparton, Tatura, Murchison, most favourably situated to benefit as they are south-east from the Rodney irrigation area. Kyabram is too well within the area to benefit fully, and Rochester and Elmore are south-west of it. As a check group we may take Violet Town, Euroa and Benalla, which are further to south-east, probably too far to benefit appreciably, but useful to throw light upon variations in rainfall distribution during the decades. Another group is Rushworth, Whroo, Nagambie and Seymour. From Waranga Reservoir the first is 2½ miles south-west, the second 6 miles south-south-west, Nagambie 15, and Seymour 33 miles south of it. These also, it may be assumed, would not be so likely to benefit as the winds reaching them from the Rodney irrigation areas would require a slight easterly component, and the other areas are rather remote. The results may be shown as follows, expressing the means for each station for the successive decades, 1885-94, 1895-1904, 1905-1914, in terms of the first as unit.

Stations assumed Unaffected.			
Echuca	1·00	·72	·78
Numurkah	1·00	·65	·74
Yarrawonga	1·00	·72	·76
Mean	1·00	·70	·76

Stations assumed Affected.			
Shepparton	1·00	·84	·91
	1·00	·75	·80
Murchison	1·00	·77	·81
Tatura	1·00	·77	·83
Mean	1·00	·76	·81
or	1·00	·78	·84
Kyabram	1·00	·71	·80

Check Groups.

South-Eastern.			
Benalla	1·00	·79	·75
Euroa	1·00	·75	·79
Violet Town	1·00	·75	·77
Mean	1·00	·76	·77

Southern.			
Rushworth	1·00	·66	·73
Whroo	1·00	·71	·75
Nagambie	1·00	·72	·76
Seymour	1·00	·77	·78
Mean	1·00	·715	·755

It is difficult to get any series of rain records in which we can place absolute confidence. The records for Shepparton prior to 1897 are based upon those from Crumlin Vineyard, which should have been sufficient, as that station is only 1¼ miles away from Shepparton, but concurrent records 1897-1904 gave a difference between them of nearly 15 per cent. of the Crumlin Vineyard record. That may have been real only for these latter years, as a 14 years' series from Mooroopna supports Crumlin Vineyard from 1891-94. However, the two are shown, the upper line giving full weight to the Crumlin Vineyard 1885-96 record, and the second treating it as needing a plus correction of 15 per cent. The truth probably lies between the two. Patched records may also account for the discrepancy between Rushworth and Seymour. The figures, however, give strong support to the assumption that stations south-east from the main irrigation area benefited by an increase of at least 5 per cent. of the annual rainfall, or of fully one inch. The last two groups tend to show that this apparent increase was not due to a difference in the rain distribution with regard to area and storm type in the successive decades.

Irrigation Increases the Means of Irrigation.

On the principle of "to him that hath shall be given, and he shall have abundance," it is more than probable that irrigation on any proper scale in Northern Victoria will increase the river supply available for conservation and irrigation.

Our mountain ranges are not high, but they are admirably placed to take advantage of improved evaporation results from the great inland area through which their waters flow. They form almost a semicircle, running south through New South Wales, and then west through Victoria. As the moistened air must almost invariably move off eastwards, it must pass over this range, which reaches its greatest average elevation in the bend where it lies most directly in the path of the eastward moving air. This additional evaporation will not only increase over the mountain slopes every rainfall coming by way of the interior, but as mists are almost a constant feature of the mountain weather, the wetting effect of these will be greatly increased, often out of all proportion to the increased humidity. It may, in fact, be in this way that the improved conditions would be most manifest. Taking, for example, the average condition of temperature and humidity at Echuca, and assuming the eastward moving air compelled to rise at least 3000 feet to cross the Australian Alps, it can be shown that up till nearly the end of October, every addition to the water vapour means so much extra condensation on the mountains.

The monthly mean 9 a.m. relative humidities at Echuca from March to October are 55, 63, 78, 86, 85, 78, 70 and 55 per cent. (A minimum of 43 per cent. is reached in January). The corresponding 9 a.m. mean temperatures are 67°, 59°, 51°; 46°, 40°, 49°, 54°, and 62°, which are also very nearly the daily mean temperatures.

Now, since wind directions north of the Divide during these months are very largely from points in the northern semicircle, and almost entirely so in rainy weather, the air from the plains is eventually driven over the mountains froming " the Divide." This involves ascent of at least 2000 feet, and with westerly components of wind direction from 3000 to 4000 feet, owing to the altitude of that portion known as the Australian Alps. The ascent being forced, the rate of cooling up to condensation level will be adiabatic. The figures for March give the ascent necessary for condensation as 3060 feet, for April 2340 feet, May 1200 feet, June 720 feet, July 720 feet, August 1190 feet, September 1730 feet, October 3000 feet. Hence, we can say that during the winter half of the year, at all events, practically every addition to the moisture in the air over the plains, shows as cloud before crossing the highlands. The consequent lowering of the level at which condensation takes place would certainly, in all weathers, increase the effectiveness of fogs in wetting mountain vegetation, and in rainy weather would increase the rainfall probably to an extent greater than the actual addition. That the former is not negligible is well shown by Dr. Marloth's experiments on the moisture collecting power of vegetation in saturated air on Table Mountain.

Other Evidences of Increased Rainfall from Local Evaporation Areas.

(1) From River Floods.

Hints of evaporation effects increasing rainfall may be obtained from a study of the average annual rainfall maps of Northern Victoria and the Riverina, which show a marked tendency for the isohyets to form loops or peaks extending down the Murray and its numerous anabranches.

(2) Rainfall Increasing Eastwards without any Apparent Cause.

The whole rainfall distribution of the Riverina and Northern Victoria suggests that the watering of large areas of country downstream from Echuca and Deniliquin has some influence in causing increased rainfall as we go eastward, since the rainfall increases without any corresponding increase in altitude. It may be as suggested by me in an article written in 1910, on the "Rainfall Distribution over Victoria," that these eastern areas derive some benefit from their being more in the way of "monsoonal" disturbances than stations further west, but this should be balanced to some extent by the greater accessibility of the western stations to oceanic influences coming by way of the Bight. At all events the differences are most remarkable. To quote from this article: "Benalla, with an altitude of 560 feet receives 26½ inches, while Wedderburn, 8 feet higher, gets only 18 inches; the altitudes of Balmattum and Sutherland are the same—565 feet—yet the former receives 25 inches, and the latter only 15½. Wangaratta, 493 feet, receives 24.8 inches and Lubeck, 488 feet, only 17.4 inches, and so on. It may be remarked, too, that the western stations are in somewhat higher latitudes, which should help them.

This phenomenon may perhaps be explained somewhat as follows: If we follow the 36th parallel from near the mouth of the Murray inland, we notice a gradual decline of the rainfall which, by the time we reach Tyrrell Creek, has dropped by more than one-third, or from 21 inches to less than 13. This is evidently due, at least in part, to the failure of local evaporating surfaces to compensate for the rain since leaving the Bight. A change now, however, begins to take place; atmospheric humidity must be increasing, for without help from land altitudes the rainfall is increasing, giving recovery at Echuca by 4 inches, and at Yarrawonga by 7, or to that near the coast line. As the increase is coincident with entry upon country always undergoing natural, and in recent years artificial, irrigation, it is reasonable to assume some connection. The unimproved Mallee areas with their uniformity of green drought-resistant scrub growth probably evaporate evenly but miserly, and, as the country is flat, this evaporation does not disturb the plane-like cloud formation usual in front of oncoming storm systems, which may be one cause of the small rainfall. But when cleared and large blocks of growing wheat or of green grass alternate with heat absorbing areas of fallowed land, we have a totally different effect. The uniformity of cloud stratification is broken by columns of heated air supplied with moisture from the green vegetation, and these tend to set up various convection centres which, when reaching the cloud level, draw upon the moist air of the cloud stratum, and cause local showers over areas which might otherwise be passed over. Thunder showers should also be of more frequent occurrence.

The same effect must, of course, result from irrigation, but with the advantage of not being limited to any season. It is quite probable, too, that these disturbances to the cloud layers rising from beneath cause local precipitation out of all proportion to the amount of moisture contributed by the evaporation areas.

(3) Persistent Increase of Monthly Rainfall during 1919 (a year of record irrigation) in Lee of Irrigation Area.

The monthly rain maps for 1919 seemed to indicate in a very striking way increased rainfalls due to irrigation, water conservation, and possibly previous flooding. The monthly isohyets showed a most persistent tendency towards increased rainfall beginning somewhere in the neighbourhood of Wentworth and Mildura, but most marked about Swan Hill and Kerang. Now, as both districts are the scenes of considerable irrigation development, and the latter of large water storages as well, a chain of lakes being kept filled for irrigation and water supply northwest from Kerang, we have an apparent cause of increased rainfall. The annual rain map for 1919 showed a strip of well-rained-on country from Euston to Mitiamo generally following the Murray, but diverging a little to southwards after passing Swan Hill. The year's rainfalls of Kerang and Mitiamo were actually above average, although the year was in general so dry that both N.E. and S.W. of this strip the rainfalls declined to 20, and even 30, per cent. below average. That this was no mere chance effect may be assumed from the fact that the monthly isohyets showed the same tendency in at least seven cases. The effect was possibly helped by heavy thunderstorm rains from Swan Hill to Kerang in February.

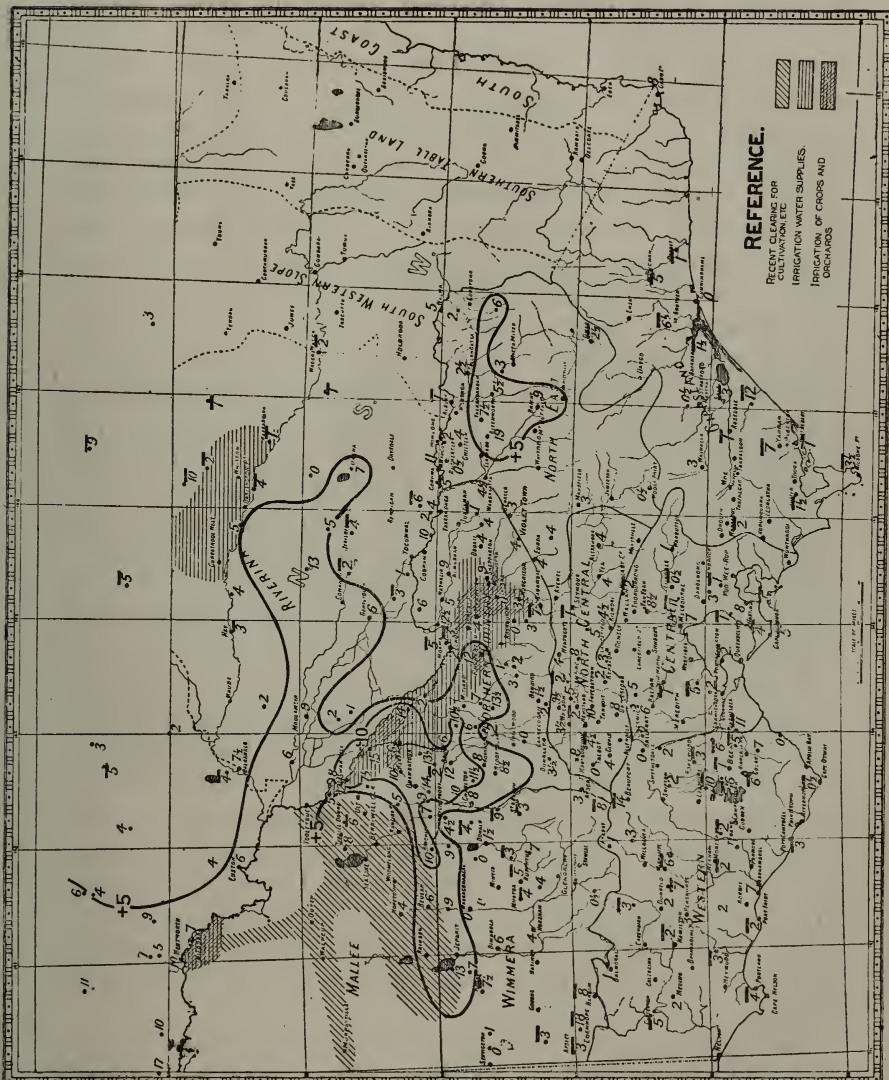
(4) Modification of Drought through Murray Floods.

To see whether there was any evidence of the Murray floods causing subsequent rainfall improvement, I selected Murray Downs, an old and, I believe, very reliable rain station near the Murray on the opposite side from Swan Hill. This station has for 20 or 30 miles north-west from it a good deal of country apparently either marshy or well supplied with lakes, filled when the Murray is in high flood. As it is probably from this direction, or from west-north-west that the storms come in dry years instead of, say, from north-north-west, as in wet years, Murray Downs should, in dry years following flood, feel some effect. Having graphed the flood levels at Torrumbarry, I selected all the dry years immediately following one of heavy flooding in its latter half. There were 22 of these, beginning with 1868. Taking annual rain totals only, and comparing with those of stations presumably less favourably placed, Murray Downs should, in these years, receive a better percentage of the average fall than should, say, Wentworth, beyond which the river trends westerly, or Moulamein and Balranald, which are on the north side of the frequently flooded areas, or Tyrrell Downs, which is to southward of them. Using the records available, comparison with Wentworth shows 14 out of 18 years favouring Murray Downs, with Moulamein 8 out of 10, with Balranald 11 out of 15, and with Tyrrell Downs 8 out of 11 in favour of Murray Downs. These necessarily give much weight to the Murray Downs records, but these are well supported by those of Swan Hill. This peculiarity of Murray Downs is not as fully felt at stations further south-east, Kaarimba being less favoured than Murray Downs in only 17 cases out of 26, Numurkah 12 out of 16, and Yarrawonga 9 out of 15. It is, of course, probable that these stations also gain from the evaporation from the Murray valley. I may say that monthly comparisons do not show any marked increased frequency of benefit at Murray Downs over these south-eastern stations, although it does with the others. This was unexpected, but may point to the principal way in which the rainfall is increased, namely, by the production of convectional centres in ordinary rain storms, or by intensifying thunderstorm action, in which case the total annual benefit at any one station might be due to a few exceptional showers.

(5) Improved Rainfall of last Ten Years only marked in connection with Irrigation Districts and Mallee Improvements.

The foregoing considerations suggested another test. The decade (1910-9) being one of considerable progress in clearing and cropping of the Mallee, and especially in irrigation and water storage in the Kerang-Swan Hill areas, the districts immediately in lee of these should show some improvement in their annual rainfall. To show this it was obviously necessary to base all rainfall comparisons upon a common period. The best seemed to be the 30-year period, beginning with 1885. This, for Victoria, gave me a little more than 200 stations, for each of which I compared the average annual rainfall of the last ten years with that for the standard 30-year period. The percentage departures from this normal were plotted on a map. The results were very striking. For almost all south of the Divide, the whole of the Wimmera, except the river drainages, and for the two Mallee stations east of Lake Tyrrell, the last ten years were slightly drier than the normal, and the same was the case with a few scattered stations in the Central North. Over the north-east and northern slopes generally there was an appreciable rise, averaging about 4 per cent. But there was one area showing a very marked rise. From Swan Hill, along the Murray to Cohuna, the plus departures ranged from 12 to 15 per cent., and thence southwards to Korong Vale they exceeded 10 per cent. The area showing these increases exceeds 2000 square miles. But this is not all. It is continued westwards in a narrow strip hugging the southern fringe of the newer Mallee clearings as far apparently as Lake Hindmarsh. The increase over this area approximates to 10 per cent. The larger increase may be assumed due to the combined effect of irrigation and Mallee improvements—the smaller to the latter only. It would, therefore, appear that the complete development of Mallee occupation will bring in a rainfall approximating to that of the lower Goulburn valley, and that irrigation will further increase this result.

On the accompanying map, kindly drawn by Mr. Curtin, the data just referred to are plotted. The numbers indicate percentage departures of the mean of the last ten years' rainfall (1910-1919), from that of the 30-year period, 1885-1914. The areas where the plus departures exceed 5 or 10 per cent. are enclosed by curving lines, which might be termed the rainfall isopleths for the latter period.



Summary.

To sum up, it may be said that there is sufficient ground for believing that the south-eastern States are all under such weather conditions that they will benefit climatically by any considerable increases in surface moisture. The clearing of the land, and the substitution of cultivation or pastures for the scrub forests on the inland plains cause, according to the evidence, some improvement of the rainfall, especially during the spring months, when the green growth results in vigorous evaporation. A more general improvement results from irrigation, which ensures growth of vegetation throughout the year. It is through this means that the greatest effects are possible. The extension of irrigation along the Murray between Echuca and Renmark, and in New South Wales, about the junction of the Darling with the Murray, it is evident, will have a not inconsiderable effect in ameliorating the climate of Northern Victoria, including the Mallee. It should also increase the rainfall on the mountains from which the irrigation water are derived. And if in connection with these, large storages of water are made from the lower Murray and Darling, say, by impounding flood waters in banked-up lakes in the same way as those of the Goulburn are impounded in the Waranga basin, the possibilities, if not almost limitless, are at least very great. I see no reason why the improvement should not be equal to what would happen if an arm of the sea like Spencer's Gulf, say, up to Menindie. It has already been shown that a reasonable result of this would be an increased rainfall of from 3 to 5 inches in the neighbourhood, even as far as 170 miles inland.

If such a result could be brought about by increasing our irrigated areas, and the necessary increase in the area of land fully irrigated can surely be made, it would be hard to put any limit upon the climatic benefits which Northern Victoria and the Riverina would derive from it. Hann has shown that in New South Wales a square mile of country carries 22 more sheep per annum with a 12-inch than with an 11-inch rainfall, and that the carrying capacity increases at a more rapid rate per inch of rain as the rainfall increases, a 17-inch rainfall, for example, enabling 70 more sheep per square mile to be carried than a 16-inch one.

Such an increase in our irrigated areas is likely, therefore, not only to be worth while in its direct effects upon the country's production, but by making further irrigation possible, to have indirect effects of very appreciable magnitude.